Greenhouse and High Tunnel Heating Alternatives

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This presentation originally developed for Amish/Mennonites

- Not all communities can use all these technologies
- But, the principles can often be adapted to the technology at hand
- You’ll see a lot of ideas... to get you thinking...
- Get a sharp pencil and think of your market
Greenhouse and High Tunnel Heating Alternatives

Special thanks to

Bob Schultheis
Natural Resource Engineering Specialist
University of Missouri Extension
What We’ll Discuss

• Site selection and energy considerations
• Structural approaches for saving energy
• Heating and Cooling Alternatives
• Technological approaches for saving energy
• Interesting applications of these principles
What is a High Tunnel?

• Unheated greenhouse; same as “hoop house”
  – Not for year-round protection or production
• Uses solar heat (back-up heaters optional)
• No electricity (fans, heaters, vents, etc.)
• Vented through sidewalls or end walls
• Drip irrigated
• Ground culture
• Single layer of plastic (6-mil)
High Tunnels - Advantages

• Extends growing season 4 weeks (maybe more)
  – Night-time air and soil temps indoors average 4°F higher than outdoors
  – Increases production & marketing opportunities
  – Offers shelter from wind, hail and insects, and can reduce disease pressure
  – Gives ability to control water supply

• Many designed as “drive through” for use of field equipment
High Tunnels - Disadvantages

• Labor-intensive; requires regular monitoring of temperatures
• Heavy rain, snow or wind can damage them
• High humidity early in growing season can lead to increased disease problems
• Construction requires more startup costs compared to conventional outdoor production
• Have to water crops, even when it rains
Greenhouse Energy Use

• Energy
  – 3\textsuperscript{rd} largest cost (~15%)
    • 70-80\% for space heating
    • 10-15\% for electricity

• The Agronomic-Economic Balance
  – Light transmission for plant growth
  – Environmental factors – humidity, temperature
  – Structure cost
  – Operating costs
Site Selection and Energy Considerations
High Tunnels - Location

• Place on 0-1% slope, well-drained, accessible site
• For stationary unit, plan to amend the soil each season or year to maintain fertility
• Orient perpendicular to the prevailing winds on your farm
  – All ventilation is manual, so you depend on the wind to ventilate
  – Face end wall toward winter wind
  – In Missouri, for our S-SW summer winds, use north-south orientation
What is the Best Location?

• Site selection factors
  – Availability of sunlight (8-10 hours/day)
  – Topography (near-level building site)
  – Wind break or hill to north (reduce heat loss)
  – Proximity to trees
  – Drainage (inside & outside)
  – Logistical convenience
  – Aesthetics

Decision usually permanent
Wind Breaks

- 15 mph wind doubles heat loss
- Wind break reduces loss ~ 5-10%
- Reduce snow accumulation
- Wind damage

Prevailing Wind
4-5 rows
Mixture: Coniferous & Deciduous

H = Mature Height of Trees

$4 \text{ to } 6 \times H$

50% speed reduction

Fast growing trees
Principles of Heat Loss

• Conduction
  – Heat conducted through a material
  – U-value – BTU/(hr-°F-sq.ft.)

• Convection
  – Heat exchange between a moving fluid (air) and a solid surface
  – Not of importance where fans are used

• Radiation
  – Heat transfer between two bodies without direct contact or transport medium – Sunlight

• Infiltration
  – Exchange of interior and exterior air through small leaks/holes in building shell
Calculating Heat Requirements

Basic equation =

sq. ft. greenhouse surface x
temperature difference (inside temp.* minus
outside temp.**) x 1.2 =
BTU/hour heat needed

*Desired temperature in greenhouse

**Average low outside temperature for area
Example Heat Requirements

Assumptions:
Free-standing greenhouse
10’ W x 12’ L x 6’ H with
6/12 roof pitch

Calculations:
Sides: $2 \times 6' \times 12' = 144$ sq.ft.
Ends: $2 \times 6' \times 10' = 120$ sq.ft.
Roof: $2 \times 5.5 \times 12' = 132$ sq.ft.
Roof peaks: $2 \times \frac{1}{2} \times 10' \times 2.5' = 25$ sq.ft.
TOTAL = 421 sq.ft.

$421 \text{ sq. ft. } \times (65^\circ F - 10^\circ F) \times 1.2 = 27,786 \text{ BTU/hour}$
heat needed

(about the same heating needs as 1,350 sq.ft. insulated home)
Example Heat Requirements

Assumptions:
Free-standing high tunnel
30’ W x 72’ L x 5’ H sidewall with 12.5’ H ~28° Gothic roof pitch

Calculations:
Ends: \[2 \times ((5’ \times 30’) + (7.5’ \times 30’/2)) = 525 \text{ sq.ft.}\]
Sides: \[2 \times (5’ \times 72’) = 358 \text{ sq.ft.}\]
Roof: \[2 \times (15.4’ \times 72’) = 2218 \text{ sq.ft.}\]
TOTAL = 3100 sq.ft.

3100 sq. ft. \times (45^\circ \text{F} - 10^\circ \text{F}) \times 1.2 = 130,200 \text{ BTU/hour heat needed}

(about the same heating needs as four 1,600 sq.ft. insulated homes)
Structural Approaches for Saving Energy
Frame Shape

Quonset
- Easy to construct
- Holds up well in wind
- Sheds snow moderately well
- Less area for tall crops
- Less expensive

Gothic
- More difficult to construct
- Stands up in wind moderately well
- Sheds snow well
- More growing space for tall crops
- More expensive

Gable
- More difficult to construct
- Does not hold up in wind as well
- Sheds snow well
- More growing space for tall crops
- More expensive

Photo credits: atlasgreenhouse.com, greenhousemegastore.com, gothicarchgreenhouse.com
Frame Shape

• Sidewall height
  – Shorter walls require less heat in spring/fall
  – Taller walls give easier equipment access
  – Taller walls easier to ventilate summer heat

• Length
  – 2:1 length to width for temperature management
Factors affecting Solar Gain

• % light = % growth
• Glazing transmittance
  – Differences between materials - (75% to 94%)
  – Condensation – can reduce light 15-25%
    • Anti-condensate films (additive)
    • Anti-condensate spray (Sun Clear®)
  – Dust
    • Anti-dust additive
Layers of Plastic

- Single layer poly
- Double layer poly
- Dead air space provides insulation (4” max.)
- Inflating devices may be AC, DC solar electric, air-driven motors, or wind-driven passive systems
Double Poly Inflation Blower

- Located on inside but drawing air from outside
- Cold air has lower humidity
- Less condensation between sheets
- Jumpers to ensure proper inflation
Inflating Devices: DC Solar Electric

Photo credit: Tim Baker

Photo credit: Tim Baker

Photo credit: Tim Baker
Inflating Devices: Air-Driven Motor
Inflating Devices: Wind-Driven
Inflating Devices: Wind-Driven

Photo credit: Tim Baker
Internal Coverings

• Think of this as a very wide double layer of poly
• More insulating effect
• Many approaches to this idea
Internal Coverings

Photo credit: Tim Baker
Internal Coverings

Photo credit: Tim Baker
Internal Coverings
Internal Coverings

Source: Ted Cary, Lewis Jett, et. al.
Internal Coverings

Source: Ted Cary, Lewis Jett, et. al.
Energy Curtain

- Insulating Blanket
- Support Track
- Edges Sealed

Source: Scott Sanford, University of Wisconsin
Energy Curtain

Can save 30-50% on heating costs
Multi-bay Approaches

- Haygrove and others
- Energy efficiency because of larger thermal mass
- Thermal flywheel effect
Multiple-Bay Approaches
Multiple-Bay Approaches
Multiple-Bay Approaches
Multiple-Bay Approaches


Multiple-Bay Approaches

Source: Ted Cary, Lewis Jett, et. al.
Multiple-Bay Approaches

Source: Ted Cary, Lewis Jett, et. al.
These are not designed to be four season structures, and will not support snow/ice loads.
Heating and Cooling Alternatives
<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Selling Unit</th>
<th>Avg. Efficiency, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>KwH</td>
<td>100-280</td>
</tr>
<tr>
<td>Natural gas</td>
<td>CCF (therm)</td>
<td>65</td>
</tr>
<tr>
<td>LP (propane) gas</td>
<td>Gallon</td>
<td>65-80</td>
</tr>
<tr>
<td>Wood</td>
<td>Cord</td>
<td>15-60</td>
</tr>
<tr>
<td>Wood pellets</td>
<td>Ton</td>
<td>80</td>
</tr>
<tr>
<td>Corn (shelled)</td>
<td>Bushel</td>
<td>80</td>
</tr>
<tr>
<td>Fuel oil</td>
<td>Gallon</td>
<td>60</td>
</tr>
<tr>
<td>Kerosene</td>
<td>Gallon</td>
<td>85</td>
</tr>
<tr>
<td>Coal</td>
<td>Ton</td>
<td>60</td>
</tr>
<tr>
<td>Biomass</td>
<td>Ton</td>
<td>40</td>
</tr>
</tbody>
</table>
Standard Heating Unit (SHU)

- One SHU = 100,000 BTUs
- Cost per SHU
  \[ \text{Cost per SHU} = \text{Fuel cost} \times \frac{100,000}{\text{(Heat Content} \times \text{Avg.Sys. Eff.)}} \]

- LP (propane) gas = $1.56/gal \times \frac{100,000}{(91,000 \text{ BTUs} \times 0.65)} = $2.64 per SHU

- Electricity = $0.09/KwH \times \frac{100,000}{(3413 \text{ BTUs} \times 1.00)} = $2.64 per SHU
## How They Rank (as of 11/2/2014)

<table>
<thead>
<tr>
<th>Heating System</th>
<th>Fuel Cost</th>
<th>Cost per SHU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air-tight stove - dry red oak</td>
<td>$ 140 / cord</td>
<td>$ 0.92</td>
</tr>
<tr>
<td>Ground-source heat pump</td>
<td>$ 0.09 / KwH</td>
<td>$ 0.94</td>
</tr>
<tr>
<td>Pellet stove - shelled corn</td>
<td>$ 3.74 / bu.</td>
<td>$ 1.19</td>
</tr>
<tr>
<td>Pellet stove - wood pellets</td>
<td>$ 200 / ton</td>
<td>$ 1.52</td>
</tr>
<tr>
<td>Air-to-air electric heat pump</td>
<td>$ 0.09 / KwH</td>
<td>$ 1.60</td>
</tr>
<tr>
<td>Natural gas forced-air furnace</td>
<td>$ 1.33 / therm</td>
<td>$ 1.66</td>
</tr>
<tr>
<td>LP gas H.E. forced-air furnace</td>
<td>$ 1.83 / gallon</td>
<td>$ 2.51</td>
</tr>
<tr>
<td>Electric resistance heat</td>
<td>$ 0.09 / KwH</td>
<td>$ 2.64</td>
</tr>
<tr>
<td>LP gas older forced-air furnace</td>
<td>$ 1.70 / gallon</td>
<td>$ 3.09</td>
</tr>
<tr>
<td>Forced-air furnace - #2 fuel oil</td>
<td>$ 3.33 / gallon</td>
<td>$ 4.01</td>
</tr>
</tbody>
</table>
Supplemental Heating High Tunnels

• In-ground heating
  – Installed before planting, buried 2” deep
    • Electric heating cables
    • Pumped hot water through hoses or pipes
  – Heats soil to set temperature to hopefully extend season

• Above-ground heating
  – Heats air around plants
  – Typically used to protect against cold nights
  – More costly than in-ground

Photo credit: Utah State University
Aftermarket Ridge Vent Modification
Aftermarket Ridge Vent Modification
Geothermal Cooling and Heating

- 8”-24” diameter tubes run underground; buried 6’-12’ deep
- Air drawn through tubes by blower
- Ground is cool in summer, therefore cool air comes out
- Hot air drawn in during summer also warms up ground
- In winter, the air is warmed by the soil
Geothermal Cooling and Heating
Techniques to Reduce Temperature

• Shading - reduce energy absorbed
  – Shade curtain
    • Fabric over top of greenhouse/tunnel
  – Shading compound
    • Permanent shade after application
    • Removed Aug – Sept

• Evaporation of water - needs relatively dry air
  – Foggers
    • Requires fine nozzles, high pressure, and clean water
  – Evaporative pads
    • Require mechanical ventilation
    • Approximately 1 gal/min. of evaporating water will cool a 30’x150’ greenhouse 15°F with 1 air change/minute

Source: Greg Brenneman – Iowa State University with modification by Tim Baker
Warning on Contaminant Gasses

• Combustion gasses from burning wood, propane, heating oil, natural gas, kerosene, or coal
  – Ethylene, sulfur dioxide, nitrogen oxides, and CO are the most common problems
  – Affects tomatoes, cucumbers, lettuce, melons, peppers, tobacco, some flowers, and bedding plants

• Plant sensitivity depends on:
  – Variety, species, age of plants
  – Light intensity and time of day
  – Humidity, watering and nutrient status
    • High humidity, well-watered plants most at risk
Ethylene Problems

• Ethylene ($C_2H_4$) is produced from incomplete combustion of fuels
• Incomplete combustion occurs with low oxygen supply to fire and wet wood
• Ethylene causes “2,4-D”-like symptoms

Photo credit: Tim Baker
Warning on Contaminant Gasses

- Never use kerosene or fuel oil heaters indoors
- Venting is required!
- Keep wood boilers outdoors
- Inspect furnace and chimney for cracks, leaks & obstructions
- Use dry wood for fuel; avoid large loads of wood with low air supply (dampers closed down)
Unvented Heater
Not a good idea
Keeping a Good High Tunnel Environment

- Some ventilation is needed for moisture control
- Air circulation within the high tunnel is important
- Ideally, natural ventilation has openings high in the roof
- ALL combustion gases must be vented outside

Photo credit: Tim Baker
Technological Approaches for Saving Energy
Stop Infiltration Leaks

• Save 3-10% in heating costs
  – Check roof and wall vents - seal tight
  – Tight cover
  – Glazing / lap seals on glass
  – Fix holes in cover
  – Weather stripping around doors
  – Door sills
  – Roll-up doors – seal for winter?
  – Ventilation louvers close tight
    • Dry lubricant - use graphite or Teflon
  – Cover unneeded fans / vents during winter
    • Foam and plastic
  – Plug gaps around foundation – earth up to sill board
  – Double/single polyethylene over glass
    = 40% savings
Polyethylene Film with IR Additive

- Reduces IR heat loss by 15-20%
- Incremental cost ~ $0.015 / sq. ft.
- Payback ~ 2-3 months / one season
- No light transmittance losses
- Diffuses light – faster, fuller more even crop growth
- Often combined with anti-condensate (AC) coating
- Installation
  - IR film on inside with anti-condensate side down (inside greenhouse)
  - Standard poly film used for outer layer

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT Plastics</td>
<td>Dura-Film 4 Thermal AC</td>
</tr>
<tr>
<td></td>
<td>Dura-Film 4 Thermal AC Plus</td>
</tr>
<tr>
<td>Covalence Plastics</td>
<td>Tufflite Infrared</td>
</tr>
<tr>
<td>Klerk’s</td>
<td>K50 IR/AC</td>
</tr>
<tr>
<td></td>
<td>K3 IR/AC</td>
</tr>
<tr>
<td>Green-Tek</td>
<td>Sunsaver</td>
</tr>
<tr>
<td>Ginegar Plastics</td>
<td>Sun Selector AD-IR / Suntherm</td>
</tr>
</tbody>
</table>

Source: Scott Sanford, University of Wisconsin
**Water for Storing Heat**

- Water is one of the best naturally-occurring materials for storing heat
- Thermal mass moderates temperature swings
- Metal or plastic barrels
  - No temperature difference
  - Metal rusts; plastic deforms
  - Plastic may hold more
- Soil will steal heat away if pad not insulated
Passive Solar Greenhouse
Solar Heated Greenhouse

- Reflective material on wall
- North wall
- Can insulate north wall with straw before placing collectors
- Heat collection system
- Thermal curtains
- South wall - glazing
- Collects reflective solar heat
Passive Solar Greenhouse

N. roof and East & West walls are insulated.

+ Triple thick plastic glazing at a 45° angle

Thermal Mass:
Water stored in tubes or drums

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**SUMMER**

Sun is higher in the sky and casts a shadow over the water-filled tubes and drums of the Botanic Gardens greenhouse helping to keep the greenhouse cool.

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**WINTER**

Sun is lower in the sky shining directly into the Botanic Gardens greenhouse directly illuminating and warming the water-filled tubes and drums. This helps keep the greenhouse warm.
Hot water under plants

• Early in the season, only two beds used
• Plastic tent over beds… works even in frost!
• Plastic removed as conditions warrant
• Water heater is 40,000 BTU
• Pumps $60, Thermostat $70
• Styrofoam under tubing for added insulation
Hot Water Under Plants

- Plastic tents over plant beds on benches
Hot Water Under Plants

- Rigid foam insulation board under pipes

Photo credit: James Quinn
Circulation fans

• Mix air to prevent stratification of air
• Reduces heating
• Dries wet leaves faster – prevents disease

Paddle fans

Jet blowers

Basket fans
Good Air Circulation is Critical

Source: Greg Brenneman – Iowa State University
Good Air Circulation is Critical
Interesting applications of these principles
Under-Bench Forced Air

- Lowers heating costs 20-25%
- Same as a 5-10°F reduction in greenhouse temperature
- Study of bottom heated tomatoes = 7% increased yields
Under-Bench Hydronic heating
Under-Bench Hydronic Heating

- Natural Convection / Thermal buoyancy
- No pumps
Hot water heating with wood furnaces

- Both indoor and outdoor systems
- Heat water and pump through pipes
- Water storage tank
- Traditionally used for radiant heat
- Solar panels can add to system
Water-to-Air Heat Exchanger
Water-to-Air Heat Exchanger

- Grower commented: More efficient, less wood
- More evenly distributed heat
- I don’t have to get up in the middle of the night to add more wood!
Water-to-Air Heat Exchanger

Photo credit: Tim Baker
Water-to-Air Heat Exchanger
Water-to-Air Heat Exchanger

Courtesy of GARN
Combustion air is drawn directly from outdoors through an internal air inlet tube (A) to the air distribution collar (B). The door (C) prevents air from being drawn from the room. The door is insulated to prevent heat loss and includes an air-cooled heat shield to prevent hot surfaces near the user. Combustion air from the collar flows through an upper and lower nozzles (D) into the combustion chamber (E). Remaining free air is mixed with hot gases before entering the ceramic secondary combustion chamber (F). Within the ceramic chamber, smoke, creosote and particulates are burned at temperatures near and above 2000 ºF. The hot gases release their heat as they move through a 5 pass tubular heat exchanger (G) submerged within a large volume of water. The cooled gases are then pulled into the Draft Inducer housing (H) and pushed out of the exhaust pipe (I).
Water-to-Air Heat Exchanger

GARN unit in south Missouri greenhouse

Source: Patrick Byers
Active Water Heating

- Assure no leaks in boiler door
- Vent flue to outdoors
- Plants close to boiler may suffer
Active Water Heating
Active Water Heating
Wood Pellet & Corn Furnace
Warmed water transplant bed

- Greenhouse for growing out transplants
- South facing
- Water tank under transplants, inside tent
- Wood heater under tank in enclosed space
- Solar gain reflected into tank as well
Chinese High Tunnel

- No additional heating, SOLAR heated.
- Single-layer plastic films.
- No automated ventilation system.
- Produce warm-season vegetables and fruits in winter.
- Labor intensive but very profitable in China.
- Changes in structure and cultural techniques through the years.
- Mechanization possible now.
Chinese High Tunnel

- It keeps the minimum temperatures at the coldest winter NIGHT above 50° F!
- Greenhouse effect: Short wave to long wave
- Heat stored in soil, thick walls (1-1.5m)
- An insulation layer (straw mat) covers the plastic film at night
- The soil temperatures are relatively high and stable.
- In colder regions, some additional heat can be used, but this is normally only done for research and breeding purposes.
Chinese High Tunnel Structure

- Three thick walls
- A thick roof (top)
- Support structure
- Plastic cover
- Insulation layer at night
Chinese High Tunnel

• Labor requirement: much better now
• Ventilation
• Disease control can be tough: high humidity and cold temperature
• Continuous cloudy and snow days can be disasters: artificial light and additional heating
Chinese High Tunnel

Located north of Springfield Missouri
High Tunnel Resources – Page 1

- High Tunnels.org
  www.hightunnels.org
- Missouri Alternatives Center (click on “H” for high tunnels)
  agebb.missouri.edu/mac/links/index.htm
- Siting High Tunnels (eXtension)
  www.extension.org/pages/18365/siting-high-tunnels
- High Tunnel Fruit and Vegetable Production Manual (Iowa State)
  https://store.extension.iastate.edu/Product/pm2098-pdf
- National Greenhouse Manufacturers Association
  www.ngma.com
- Energy Self-Assessment website (NRCS)
  www.ruralenergy.wisc.edu/default.aspx
• Passive Solar Greenhouse (University of Missouri)
  bradford.cafnr.org/passive-solar-greenhouse/
  bradford.cafnr.org/greenhouse-materials/
• High Tunnel Tomato Production
  extension.missouri.edu/p/m170
• High Tunnel Melon and Watermelon Production
  extension.missouri.edu/p/m173
• Watering and Fertilizing Tomatoes in a High Tunnel
  http://extension.missouri.edu/p/G6462
Questions?